SBIR S2.05 Development

GSFC Optics Branch Technologies

Topic: S2: Advanced Telescope Systems

Subtopic: S2.05: Optics Manufacturing and Metrology for Telescope Optical Surfaces

Solicitation Development Objectives

- **Subtopics with science traceability, infusion potential**
  - Should articulate specific benefits for NASA missions and goals
  - When possible, should trace to science mission requirements
- **Development tasks appropriate to small businesses**
  - No “critical path” deliverables or large, complex systems
  - End product/capability should also provide a path to an attractive return on investment for small business
- **Planning for approximately three Phase 1 and one Phase 2 awards with superior infusion potential per Subtopic**
  - Topics that are too broad or too narrow may miss this goal
  - Good proposals should get “cradle-to-grave” support from NASA

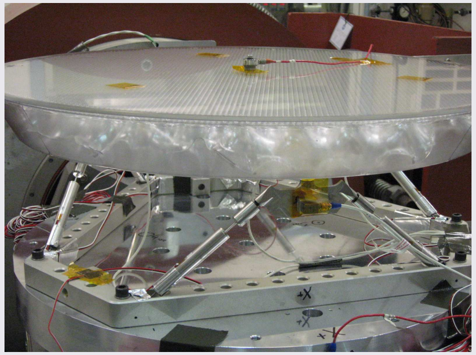
Optics Branch Key Technologies

Large Optics: The Optics Branch has developed specialized mirror mount designs for a highly light weighted primary mirror to maintain its position to the micron level without distorting it. The primary mirror is from ITT, and is a ULE fused silica ultra-lightweight sandwich mirror.

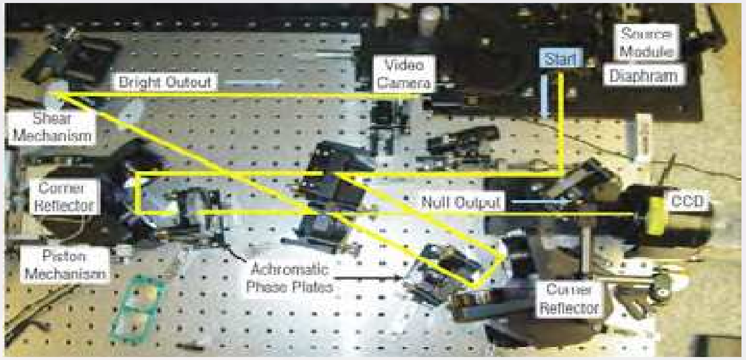
Visible Nulling Coronagraph Technology Development: The Extra Solar Planetary Imaging Coronagraph (EPIC) is a mission concept to directly detect and characterize extra-solar planets. The VNC is a critical technology to realize EPIC, and relies on nulling technology to separate starlight from planet light.

Wavefront Sensing: This technology supports a variety of optical characterization and control tasks that utilize image based optical wavefront sensing. Using the image based approach, optical sensing hardware is replaced by a computational approach where a digital camera serves as the wavefront sensor.

Development of an Ocean Radiometer for Carbon Assessment (ORCA) prototype: This recently funded IIP proposal is designed to meet the future measurement requirements of the NASA Ocean Biology and Bio-Geochemistry program. Funds are provided to build an ORCA prototype consisting of a rotating telescope assembly and an internal spectral calibrator subsystem.



Ultra-Lightweight Mirror



Visible Nulling Coronagraph Test Bed

GSFC Optics SBIR Success Stories

SBIR Optical Measuring Technique Applied to Projects:

Under the PY03 SBIR phase II project, Bauer Associates, Inc. of Wellesley, MA developed a working prototype instrument that utilizes a non-interferometric, optical technique for measuring absolute aspheric shape over the full surface of large mirrors to the nanometer level, without the need for known reference surfaces. Recently, Bauer worked with the Smithsonian Astrophysical Observatory to use the prototype to measure the surface of NASA's High- Resolution X-Ray Explorer (HIREX) Pathfinder mirror. COTR: Timo Saha (GSFC, 03/23/08)

Goddard Innovation Fund to Advance STTR Technology:
The Phase III to Trex Enterprises Corporation and University of Alabama at Huntsville is an extension of the PY03 STTR Phase II project entitled "High Volume, Low-Cost Production Process for High-grade Silicon Carbide Optics." The specific objective is to demonstrate corrective grinding and figuring of a SiC mandrel. This would enable the demonstration of x-ray mirror fabrication from a SiC mandrel and comparison of x-ray mirrors from a SiC mandrel and from a fused quartz mandrel. The targeted application is Constellation-X project. The Constellation-X Observatory is a combination of several X-ray telescopes working in unison to generate the observing power of one giant telescope. COTR: Dave Content. (GSFC, 06/22/08)

SBIR Mirror Concept Enables EPIC Mission Concept:
Advances in MEMS and control electronics technology based on a PY05 SBIR Phase II project with Iris AO, Inc. enable the scaling up of extreme-precision MEMS deformable mirrors for EPIC (Extrasolar Planet Imaging Coronagraph) concept. EPIC is a Discovery Mission concept designed to directly image and characterize extrasolar gas giant planets at typical distances of 2 to 20 AU from the parent star. COTR: Rick Lyon. (GSFC, 8/24/08)

S2.05 Subtopic Description

S2 Advanced Telescope Systems

S2.05 Optics Manufacturing and Metrology for Telescope Optical Surfaces

This subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include:

JDEM concepts (http://universe.nasa.gov/program/probes/jdem.html),
IXO (http://ixo.gsfc.nasa.gov/),
LISA (http://lisa.gsfc.nasa.gov/)
ICESAT (http://icesat.gsfc.nasa.gov/), CLARREO, and ACE

Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period. Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges. For example, mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

Of particular interest is the area of x-ray optics metrology, including the evaluation of the optical quality of x-ray mirrors and substrates; the general characterization of x-ray mirrors; and the development of new metrology measurement techniques and instrumentation for x-ray mirrors.

S2.05 Subtopic Description

By the end of a Phase 2 program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

*Interferometric nulling optics for very shallow conical optics used in x-ray telescopes.
*Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree.
*Low stress metrology mounts that can hold very thin optics without introducing mounting distortion.
*Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
*In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.
*Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
*Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S2.05 Award Statistics

	Phase 1	Phase 2
2005	21% (6/29)	67% (4/6)
2006	25% (2/8)	100% (2/2)
2007	38% (3/8)	33% (1/3)
2008	54% (7/13)	
Total	31% (18/58)	64% (7/11)

2005 SBIR

Phase 1 | 29 Submitted | 6 Selected

- S4.04-8021 High Resolving Power Volume Diffractive Gratings for 400-2700 nm Spectral Range, OptiGrate
- S4.04-8169 Fast Picometer Mirror Mount, Nightsky Systems, Inc.
- S4.04-8389 High-Density Diffraction Imaging and Non-Imaging Grating Elements for EUV and X-ray Spectroscopy Fabricated by DUV Reduction Photolithography, LightSmyth Technologies
- S4.04-8886 Nonintrusive Optical Thermometers for Real-Time Control of Fabrication Processes, Los Gatos Research
- S4.04-9332 Extreme-Precision MEMS Segmented Deformable Mirror, Iris AO
- S4.04-9574 Edge Control in Large Segmented Optics using Zeeko Polishing Technology, Zeeko

Phase 2 | 4 Funded

- S4.04-8021 High Resolving Power Volume Diffractive Gratings for 400-2700 nm Spectral Range, OptiGrate
- S4.04-8389 High-Density Diffraction Imaging and Non-Imaging Grating Elements for EUV and X-ray Spectroscopy Fabricated by DUV Reduction Photolithography, LightSmyth Technologies
- S4.04-8886 Nonintrusive Optical Thermometers for Real-Time Control of Fabrication Processes, Los Gatos Research
- S4.04-9332 Extreme-Precision MEMS Segmented Deformable Mirror, Iris AO

Phase 1 | 8 Submitted | 2 Funded

S4.04-8127 Programmable Relaxor Open-Loop Mirrors Using Imaging Spatial Encoder (PROMISE), Xinetics, Inc.

S4.04-9893 An Instrument for Inspecting Aspheric Optical Surfaces and Components, MetroLaser, Inc.

Phase II | 2 Funded

S4.04-8127 Programmable Relaxor Open-Loop Mirrors Using Imaging Spatial Encoder (PROMISE), Xinetics, Inc.

S4.04-9893 An Instrument for Inspecting Aspheric Optical Surfaces and Components, MetroLaser, Inc.

2007 SBIR

Phase 1: 8 Submitted 3 Funded

S2.05-8391 Reactive Atom Plasma Processing of Slumped Glass Wedges, RAPT Industries, Inc.

S2.05-9744 The Affordable Pre-Finishing of Silicon Carbide for Optical Applications, Creare, Inc.

S2.05-9745 Novel Materials for Mirror Substrate in Space Telescopes, Advanced Materials Technology, Inc.

Phase 2: 1 Funded

S2.05-9744 The Affordable Pre-Finishing of Silicon Carbide for Optical Applications, Creare, Inc.

Phase 1 13 Submitted 7 Funded

S2.05-8681 High Reflectivity, Broad-Band Silver Coating, Surface Optics Corporation

S2.05-8983 Low-Stress Iridium Coatings for Thin-Shell X-Ray Telescopes, Reflective X-ray Optics, LLC

S2.05-9001 Application of Zeeko's Novel Random Tool Path for Improvement of Surface PSD, Zeeko Technologies, LLC

S2.05-9323 Submicron Composite Mirror Replication, DR Technologies, Inc.

S2.05-9500 Super Polishing of Aluminum 6061-T6 Mirrors, Microengineered Metals, Inc.

S2.05-9876 High-Speed Scanning Interferometer Using CMOS Image Sensor and FPGA Based on Multi-Frequency Phase-Tracking Detection, Nanowave

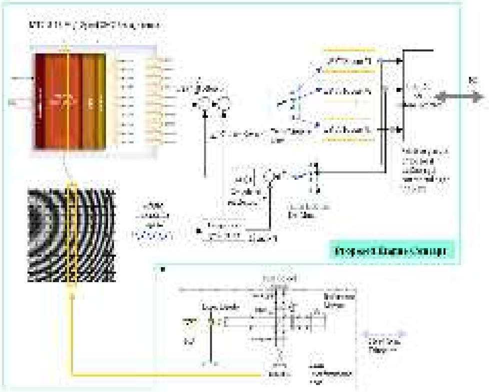
S2.05-9938 RAP Figuring Slumped Mirrors to Remove Mid-Spatial Frequency Errors, RAPT Industries, Inc.

NASA SBIR/STTR Technologies

S2.05-9876 - High-Speed Scanning Interferometer Using CMOS Image Sensor and FPGA Based on Multi-Frequency Phase-Tracking Detection

Tetsuo Ohara

NanoWave, Inc- Sutton, Ma



Identification and Significance of Innovation

Although a sub-aperture scanning laser interferometer holds good potential as an in-situ metrology tool for large optics, optical interferometers in general rely on a temporal interference image formed on an image sensor for the phase map calculation, resulting in a limited spatial phase resolution and scanning speed.

In this proposal, NanoWave's Scanning Probe Position Encoder technology will be independently applied to each pixel on the high-speed CMOS image sensor in order to take an advantages of the multi-frequency phase tracking detection with a highly efficient FPGA signal processing method. This new solution can transform many laser interferometers into high-speed and sub-nanometer scanning metrology tools with only minor modification.

Expected TRL Range at the end of Contract : 4

Technical Objectives

1. Verilog code optimization for the proposed system and code implementation on a low cost, single FPGA chip.
2. Demonstrate the performance of proposed system, specifically:
   - I. Sensor bandwidth (real-time measurement) >500Hz
   - II. Phase resolution at 18 bit per 2π rad
   - III. Maximum scanning speed > 1m/sec
   - IV. Dynamic range of more than 1.03e5 rad

Work Plan

1. FPGA signal processing coding for multi-frequency phase tracking detection
2. Construction of virtual Signal Generation Platform and simple test fixture
3. Testing and performance verification.

NASA Applications

1. In-situ scanning metrology for large Optics
2. In-situ metrology for micro Optics

Non-NASA Applications

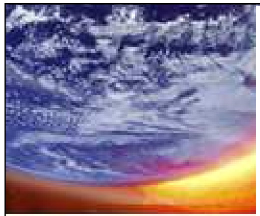
1. Data storage metrology (HDD disk flatness etc)
2. Film thickness measurement
3. MEMS (Metrology and process monitoring)
4. Semiconductor wafer process monitoring
5. Optical coherent tomography
6. Laser Doppler vibration sensor

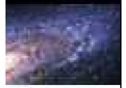
Firm Contacts

Tetsuo Ohara (Principal Investigator)

tetsuo@nanowave.com

NON-PROPRIETARY DATA





NASA SBIR/STTR Technologies

SBIR STTR

S1.05-9938 RAP Figuring slumped mirrors to remove mid-spatial frequency errors

PI: Pradeep Subrahmanyan

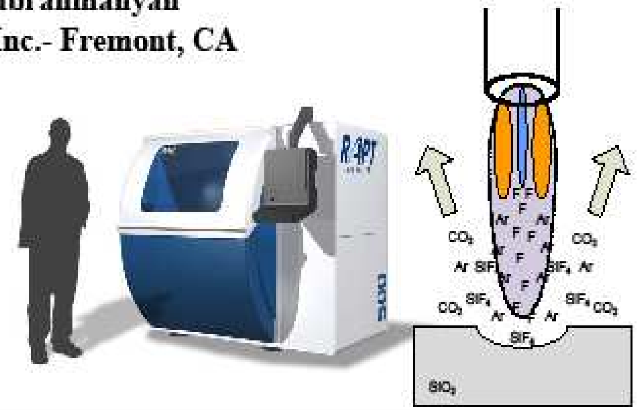
RAPT Industries, Inc.- Fremont, CA

Identification and Significance of Innovation

Future lightweight grazing incidence mirrors such as Constellation-X require significant amounts of optical area. To accommodate this in a grazing incidence design, extremely thin mirrors are formed in concentric shell configurations. A "Fabricate and Assemble" technique has been demonstrated with such thin, lightweight shells. However, the optical surface is found to contain a significant amount of mid-spatial frequency errors. It is proposed to demonstrate a sub-aperture figuring technique that does not impart mid-spatial frequencies to the optical substrate geometries planned for integration into next-generation X-ray telescopes.

The RAP process is well suited for processing lightweight optics given the non-contact nature of the process. We plan on adapting the RAP process to the optical figuring of the slumped mirrors to remove the mid-spatial errors resulting from the release agent.

Expected TRL Range at the end of Contract (1-9): 3-4



Technical Objectives and Work Plan

The main technical objective is to demonstrate the ability of the RAP process to impart minimal mid-spatial frequencies onto a flat substrate intended for use in the Constellation-X program during neutral removals and figuring to a flat prescription. The secondary objectives are to: 1) Characterize the mid-spatial frequency errors on slumped optics. 2) Determine the requirements on Gaussian spot size as required. 3) Determine the right architecture for varying spot size for implementation in phase II. In order to achieve these three objectives, RAPT Industries, Inc. divided the project into two major tasks:

Task 1: Figuring of optical surface – Two 4x4 BK7 flats will be both figured and treated to neutral removals to better understand the process transfer function.

Task 2: Characterization of mid-spatials – Work closely with NASA personnel to determine errors as a function of spatial frequency on real slumped mirrors (at least two designs) and develop the right Gaussian spot sizes to figure such mirrors in a time-effective manner. The actual implementation of the developments will be in Phase II.

NASA and Non-NASA Applications

Key NASA applications that could immediately use the technology are those involving high energy X-ray telescopes such as NuSTAR and Constellation-X. The technology developed is also applicable to other NASA programs that seek to minimize payload without sacrificing sensor performance. Besides X-ray optics, the technology can be used on other glass based astronomy programs.

Other optics applications involve lithography, surveillance tracking and fire-control systems with various commercial and DoD agencies. Making precision surfaces with a high aspect ratio is a common problem across optics, semiconductors, compound semiconductors, photo-voltaics etc. The high aspect ratio results from a need to reduce mass (as in the case of lightweight mirrors), improve device performance/packaging (as in semiconductors), decrease costs (as in photo-voltaics). The methods developed in Phase 1 can be applied to the rapid manufacturing of such surfaces in these other areas. RAPT Industries, Inc. has already commercialized the edge cleaning of semi-conductor wafers through a licensing arrangement with Accretech, USA.

Firm Contacts

Pradeep Subrahmanyan, Ph.D., President/CEO TEL: 510-933-1001

NON-PROPRIETARY DATA

NASA SBIR/STTR Technologies

S2.05-9500 – Super-Polishing of Al 6061-T6 mirrors

PI: Susan Wilson, PhD
Microengineered Metals, Inc. – Yorkville, IL

Identification and Significance of Innovation

- Al 6061-T6 mirrors have been super-polished to <5 Angstroms rms surface roughness (@20x).
- The technology addresses NASA's need for a cost-effective Al polishing method that removes diamond point turning (DPT) grooves thereby enhancing optical properties and extending optical utility.
- Super-polishing improves signal to noise, reduces beam dispersion, eliminates need for overcoating with Nickel or elemental Aluminum.
- Successful transfer of process onto 3D platform would enable the manufacturing of more advanced mirrors (aspheres).

Expected TRL Range at the end of Contract (1-9): TRL 3-4

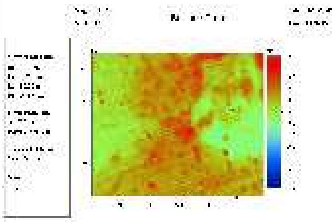


Fig 1. Diamond point turning grooves @ 20X

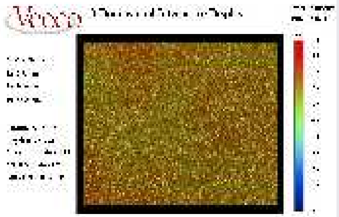


Fig 2. Super-polished Al 6061-T6 @ 20X

Technical Objectives

- Demonstrate the feasibility of transferring the 2D super-polishing process for Al 6061-T6 planar mirrors onto the Zeeko IRP200 3D polisher, successfully polishing away DPT grooves and achieving < 10 Angstrom rms surface roughness on 2" planar mirror.
- Polish a 2-inch Al 6061-T6 f/8 sphere removing all DPT grooves.

Work Plan:

- Utilize DOEs to identify best tool settings to minimize surface roughness and remove DPT grooves.
- Develop robust polishing process that minimizes noise.
- Test random tool path algorithm to minimize polishing tracks.
- Super-polish f/8 sphere to demonstrate 3D technique.
- Run initial test of Zeeko-jet polishing with super-polishing slurry

NASA Applications:

- IR mirrors for SAFIR
- X-ray mirrors for IXO
- Cryogenic mirrors for TPF
- Repolishing of existing DPT mirrors

Non-NASA Applications:

- Concentrating Solar Power mirrors
- Remote sensing, reconnaissance, imaging mirrors
- Fast steering mirrors
- Mirrors for high-contrast microscopes

Firm Contacts:

Susan Wilson, PhD, PI, CEO, Microengineered Metals, 630-553-2923
Robert Banwart, MBA, COO, Microengineered Metals, 740-277-9610

NON-PROPRIETARY DATA

In Conclusion

GSFC has a robust and productive SBIR program in the Optics area, with high quality proposals being submitted every year, leading to advances in key Optics Technologies.